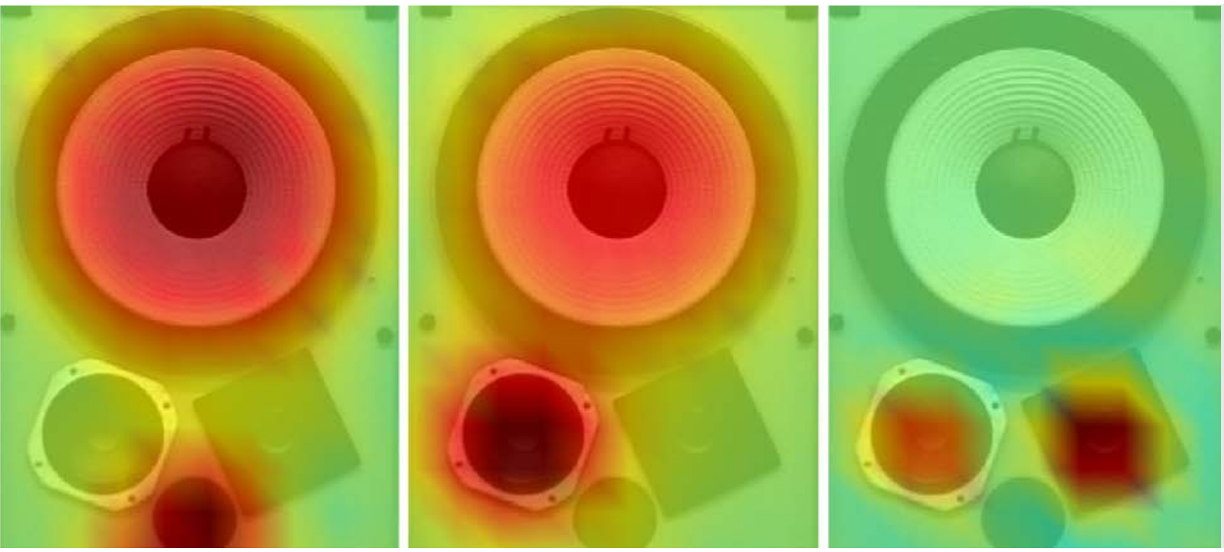
A Powerful Tool for Acoustic Imaging



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Scanning an Ultra-light Membrane to Image Acoustic Fields

Researchers at the INSA Laboratory of Vibration and Acoustics in Villeurbanne (France) are currently developing a new measurement device to obtain acoustic particle velocity maps from laser measurements. The technology is based on suspending an ultra-light membrane in the acoustic field under study, and measuring its velocity with a laser vibrometer. The challenge lies in choosing a suitable material for the membrane and optimizing the experimental conditions used to maintain it.

Images of Acoustic Fields Obtained using Laser Vibrometry

Traditionally, images of acoustic fields are obtained by scanning a plane with a microphone or using a microphone array. The result is a hologram which represents the acoustic field at a given frequency with respect to magnitude and phase. The novel technique presented in this article uses a laser vibrometer focused onto an ultra-light membrane. The membrane is placed in an acoustic field and its velocity is measured by using the scanning laser vibrometer. A hologram of normal acoustic velocity is obtained using a mass-correction operation. This allows the application of standard post-treatments such as near-field acoustic holography or acoustic power assessment.

The principle behind the measurement technique relies on the fact that the vibrating velocity of a membrane suspended in the air is equal to the normal acoustic velocity of the sound field. Measurement of the membrane velocity gives the normal acoustic particle velocity on a planar surface. There are two main disadvantages of this approach: it is destructive and the membrane itself modifies the sound field. As a result, the measured velocity differs from the trye acoustic velocity without a membrane. For example, the velocity of a 20g/m² membrane excited by a plane wave in normal incidence is attenuated by 10% (-0.5 dB) at 1500 Hz, and 50% (-3 dB) at 4500 Hz. The mass of the membrane can be corrected but the wave reflected from the membrane can induce additional perturbations. This means that the membrane must be as light as possible

Other membrane design considerations are:

- the membrane must be suspended with minimal tension to avoid membrane modes
- the membrane must scatter the laser beam with a reasonable diffusivity
- the membrane must deflect linearly

The Loudspeaker

In Figure 1, the velocity field in the near-field of a loudspeaker is depicted. The membrane is placed 2 cm in front of a 3-way loudspeaker with a bass reflex opening. The acoustic normal velocity fields shown in Figure 1 are 70 Hz, 500 Hz, and 9 kHz. The bass reflex mode is illustrated in the first map with the woofer and mid-range speakers at 500 Hz and the tweeter at 9 kHz. This example illustrates the wide frequency range that can be achieved by the technique.

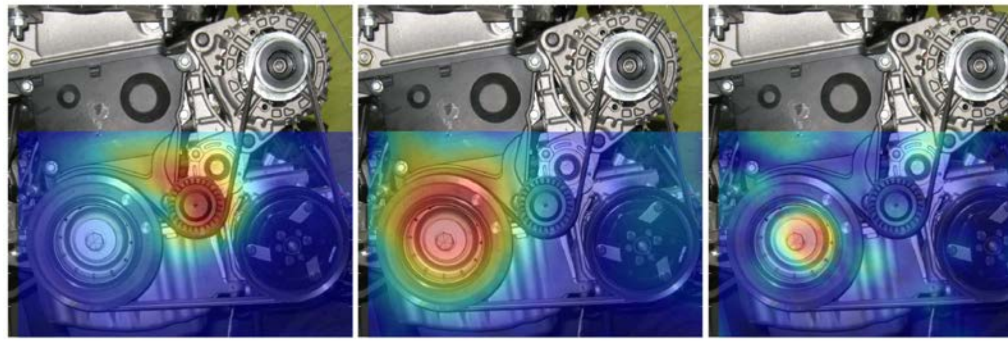

Figure 2: RMS velocity maps in the near-field region of a gasoline engine: left, 600 Hz; center, 1100 Hz;– right, 4200 Hz.

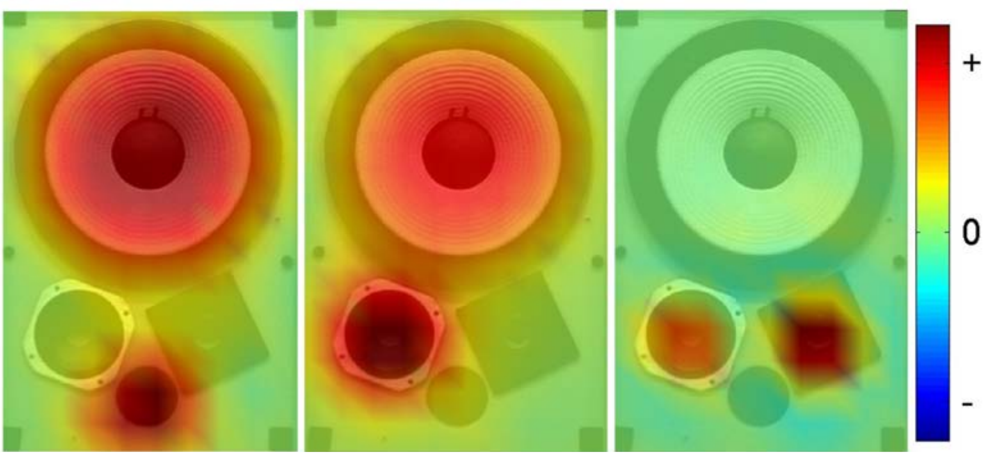

Figure 1: Velocity maps in the near-field region of a loudspeaker: left, 70 Hz; center, 500 Hz; right, 9000 Hz.

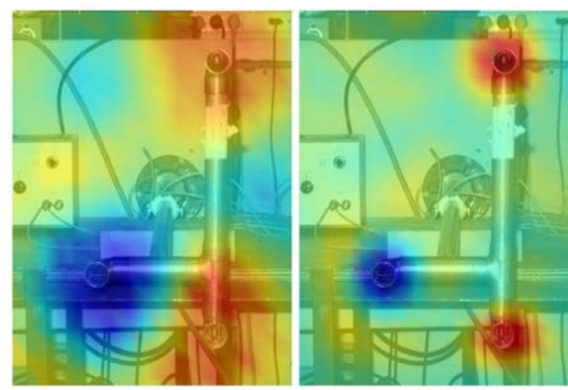

Figure 3: Left: velocity of the membrane at 4 cm distance from the acoustic source at 2700 Hz. Right: back-propagated velocity field in the source plane using NAH. The chromatic scale represents negative, zero and positive acoustic values.

Acoustic Velocity in the Near-field region of a Gasoline Engine

In Figure 2, an industrial application of the technique is shown using a gasoline engine. A membrane is placed in the near-field region of the belt side of a gasoline engine when idling. Different sources of vibration are easily identified depending on the frequency; the roller tensioner at 600 Hz; the whole crankshaft pulley at 1100 Hz; and only the inner part at 4200 Hz.

Membrane-based Near-field Acoustical Holography

Planar near-field acoustic holography (NAH) is a method used to back-propagate the acoustic field measured on a planar surface. The technique requires a 2D discrete Fourier transform (DFT) of the measured acoustic pressure or velocity field. The advantage of membrane-based NAH is that the mass of the membrane can be taken into account to correct each component of the 2D DFT. An experimental test of membrane-based NAH has been used to validate the approach. The test sample is a copper tube with 3 openings on the front which behave like correlated monopoles, and one opening on the back of the device which is coupled to an acoustic source (see Figure 3).

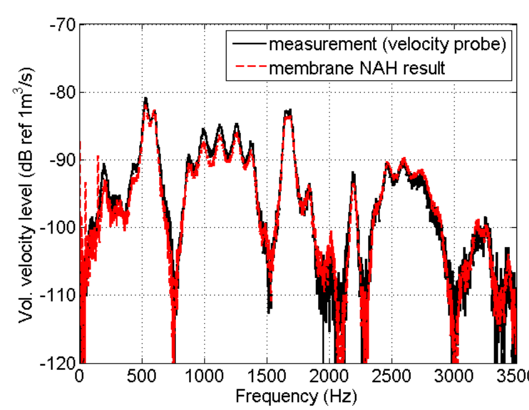

Figure 4: Volumetric velocity of one of the three openings as a function of the frequency

Conclusion

An ultra-light membrane combined with a scanning laser vibrometer provides a powerful acoustic measurement system. Finding the optimal membrane is key - one that displays optical reflectivity but is acoustically transparent. The data presented here show that the approach has potential for use in acoustic imaging applications.

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